Freeboard Combustion of High Ash Coals in Fluidised Bed

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1.0 Introduction :

Fluidised Bed Combustion (FBC) systems for firing high ash coals and low grade fuels are gaining wide acceptance in industrial and utility sectors in India due to abundance of such fuels. The resources of all types of coals in India is estimated to be 192 billion tonnes. As much as 40% of the resources contain more than 32% ash. Fluidised bed combustion is the only option to utilise these fuels in an economically viable and environmentally acceptable manner. Fluidised bed combustion has a number of attractions for steam generation. The major advantages include excellent combustion of wide variety of fuels, low pollutant emissions and increased heat transfer rates.

Commercial application of fluidised bed combustion for steam generation started in the late 70's in India. Present fluidised bed combustion boilers in India are of conservative design due to lack of information on the combustion characteristics of high ash coals in FBC. Further, since no sorbent is required with Indian coals due to their low sulphur content, the bed depths are much shallower compared to the deep beds adopted for high sulphur Western coals.

2.0 Role of Freeboard in Fluidised Bed Combustion Furnaces :

A critical grey area of FBC technology for boiler application is the design of the free board zone of the fluidised bed combustor. Free board zone is the region between the top of the fluidised bed and the first convective surface. Its primary function is to allow particles ejected from the bed to decelerate and fall back into the bed. It also provides additional gas to gas and gas to solid contact so that combustion of volatiles and char particles can take place. The phenomenon of free board combustion is a result of combustion of elutriated solids and the combustion of the unburnt volatiles. Proper estimation of the free board combustion is of vital importance in optimum design of fluidised bed combustion.

3.0 Free Board Combustion Phenomenon :

Bubble eruption at the bed surface is responsible for the solids release into the free board. Solids contained in the leading bulge portion of the bubble burst out as the bubble erupts at the free surface and are thrown up into the free board.

The possibility of incomplete combustion of volatiles in the bed and escaping to the free board also exists. Volatiles which are released during the time the coal particles are carried from the feed point to the top of the bed will be contained in an axially symmetric region centred on a vertical axis through the feed point. If sufficient oxygen is not supplied to this volatile release zone, the volatiles will escape the bed and burn in the free board.

The phenomenon of free board combustion is the net result of combustion of char in the elutriated solids and the combustion of unburnt volatiles escaping from the bed into the free board.

4.0 Free Board Combustion Model :

While individual models are available for estimating the elutriation rates and for volatile release in fluidised bed, stand-alone model to predict the free board combustion which can be directly applicable for boiler furnace design are very rare. With this purpose in mind, a model to prdict the free board combustion taking into account coal properties, coal size distribution, superficial fluidisation velocity & bed temperature has been evolved. This model has been developed for underbed fuel feeding system wherein the fuel is injected into the bed pneumatically through multiple feed points located in the air distributor. Considering the vigorous mixing and nature of combustion in fluidised bed, it is assumed that no carbon monoxide formed due to partial combustion of solid carbon in the bed escapes the bed. It is assumed that the volatile combustible portion escaping the fluidised bed, completely burns in the fece board zone which is a reasonable assumption.

Elutriation rate is determined by the following correlation :

$$\frac{E}{\rho_g\, U_o} = 2.19 \times 10^{4} \left[\frac{\mu_g}{\rho_g\, U_o\, dp}\right]^{0.55} \left[\frac{U_o^2}{g\, di}\right]^{1.32} \left[\frac{\rho_g}{\rho_s - \rho_g}\right]^{2.6}$$

This correlation includes effects of viscous force, particle momentum & buoyancy force and hence more representative among the models for elutriation. The carbon in elutriated particle depends on the extent of combustion which has taken place in the fluidised bed. The specific burning rate is given by $1/(1/hm + 1/Rc)$, where hm is the mass transfer coefficient and Rc the reactivity. Mass transfer coefficient is determined based on Sherwood number and diffusivity. Reactivity is estimated based on rate constants for bituminous char. The same model is used for determining the carbon burn out in freeboard by suitably apportioning the rate controlling parameters.

For estimation of volatile combustion in the bed, a plume model based on instaneous release of volatiles and lateral diffusion is used. The cross-section over which the volatiles are released is determined by the solid diffusivity Dr which is estimated by using the correlation,

$$Dr = \frac{3}{10}\ \frac{\delta}{1-\delta}\ \frac{U_{mf}\, D_b}{\varepsilon_{mf}}$$

Extent of combustion of volatiles in the bed is dependent on the oxygen availability in this volatile release zone and the unburnt volatiles escape into the free board where the environment is conduckive for full combustion.

Enclosed figure shows the schematic of the model.

5.0 Experimental Facility & Test Details :

A test facility located in the R&D complex of BHEL, Tiruchi, was used for conducting the experiments. This facility consists of a 1m x 1m cross-section refractory lined combustor with a combustor height of 11m. Tube bundles are provided in the fluidised bed to extract heat and maintain the bed temperature. Under bed coal feeding system is provided. A shallow bed is adopted with an expanded bed height of 600 mm. The combustor is designed for balanced draft operation in the free board.

Tests were conducted with high ash sub-bituminous coals normally available for FBC boilers as fuel. The fuel rate was maintained constant in each test and the air flow rate was adjusted to obtain the required fluidisation velocity. Once the required velocity was achieved final adjustment of the coal feed rate was performed to maintain excess air levels within the selected range. After stabilising at each condition, tests were conducted for a period of 4 hours and data were collected.

6.0 Test Results & Analysis :

Free board combustion as a percentage of heat input was computed for each of the test data. Free board combustion ranged from 6 - 9% for bituminous coal depending on the superficial fluidisation velocity. The proposed mathematical model was used to predict the free board combustion under simulated condition of test runs. Figure shows the predictions from the model and the test values. It can be seen that the free board combustion computed from the test data generally tallies with the prediction. The free board combustion values are on the higher side compared to the values obtained by researchers for Western coals. Reason can be attributed to less fines and coal characteristics considered in the latters' experiments.

Also indicated are the variation of free board combustion with parameters like bed temperature,fines, fluidisation velocity and excess air. Prediction of free board combustion with variations in operating fluidisation velocity, average bed temperature, percentage fines (<1 mm) and excess air are commensurate with the operating expericce in fluidised bed combustion boilers over the ranges considered.

7.0 Conclusion :

A model has been developed to predict the free board combustion in fluidised bed boilers. This model has been validated for application to high ash Indian coals . The proposed model can be used for sizing the free board region of fluidised bed boilers in an optimum manner.

8.0 Acknowledgement :

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9.0 Abbreviations :

E	: *Elutriation Rate Constant*	di	: Size Fraction
μ_g	: Viscosity of gas	ρs	: Solid Density
ρg	: Density of gas	δ	: Bubble Voidage
U_o	: Superficial Gas Velocity	db	: Bubble Dia
dp	: Mean Particle Dia	ε_{mf}	: Voidage at Minimum Fluidisation Velocity

10 References :

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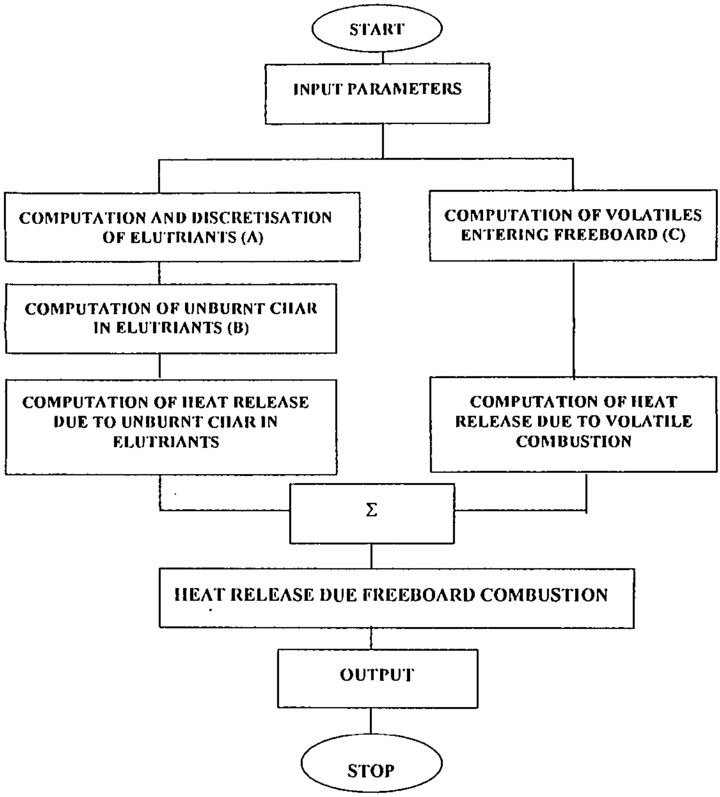
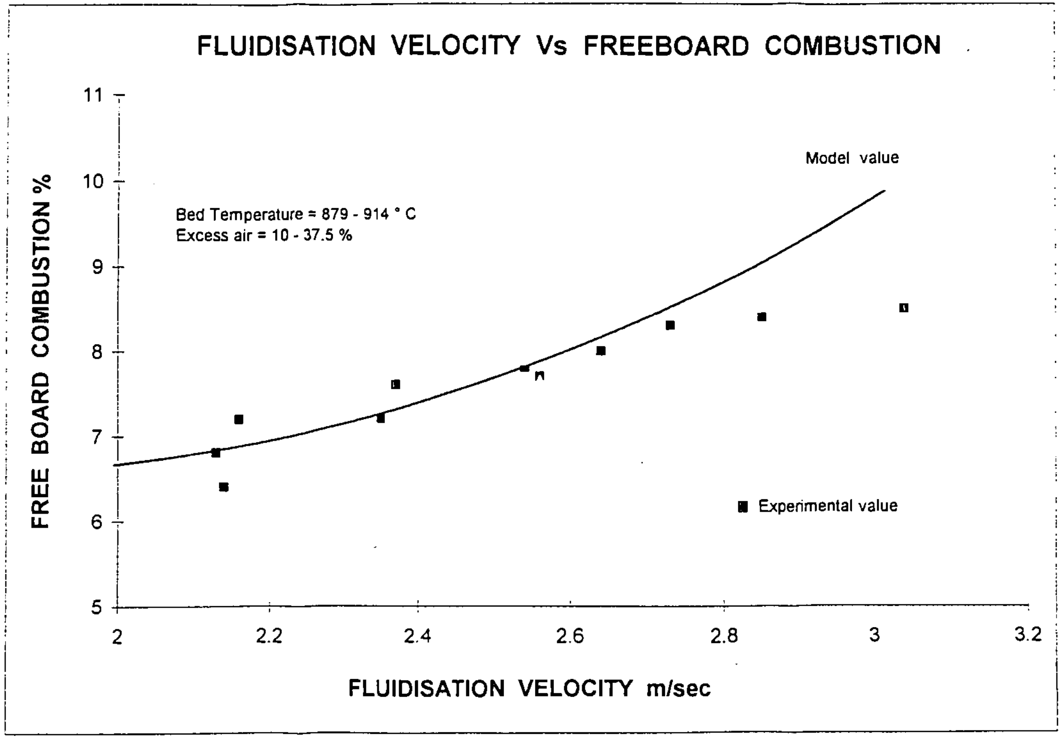
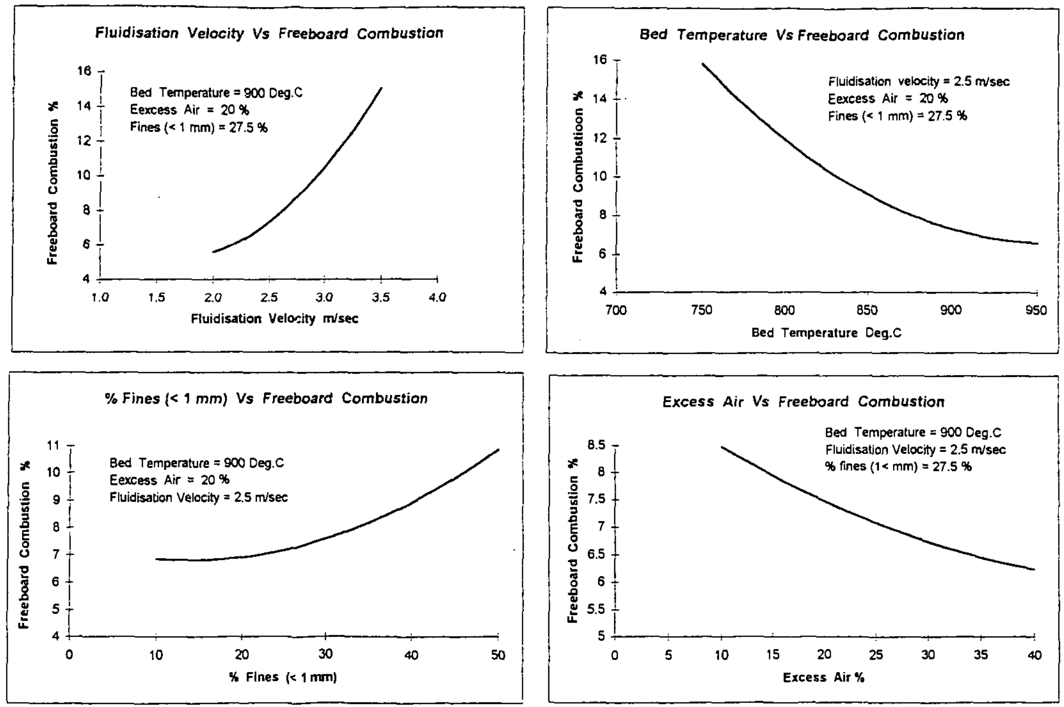
BASIC MODEL FOR COMPUTING FREE BOARD COMBUSTION





FLUIDISATION VELOCITY Vs FREEBOARD COMBUSTION
FREE BOARD COMBUSTION %
11
10
9
8
7
6
5
2
2.2
2.4
2.6
2.8
3
3.2
FLUIDISATION VELOCITY m/sec
Bed Temperature = 879 - 914 ° C
Excess air = 10 - 37.5 %
Model value
Experimental value



Model Predictions